Report on Model 330 Interconnection Testing and Certification

1.0 Introduction

The following Report is a summary of the tests that were conducted at Capstone Turbine Corporation test facilities and witnessed by Underwriters Laboratories Inc. (UL) to demonstrate compliance of the Model 330 with the utility-interactive requirements of UL 1741. This Standard is a safety standard that focuses on the interconnection between an inverter (our Microturbine) and the utility grid. The Standard is harmonized with IEEE 929, and is the basis for the California Rule 21 certification requirements.

In addition to the tests that UL witnessed at our facilities, UL 1741 compliance also requires that we test the dielectric voltage withstand ability and the protective relay functions on every DPC produced. These tests are outlined in an appendix to our UL File, and are attached to this document as Exhibit A.

A formal copy of the UL Test Report is attached to this document as Exhibit B, and serves as a reference to the information contained in this Report.

2.0 Summary of Results

Test	UL 1741 Reference	Date(s) Conducted	Result	Report Section
Utility Disconnect Switch	Section 39.1	N/A	Pass	3.1
Field Adjustable Trip Points	Section 39.2	N/A	Pass	3.2
Field Adjustable Trip Points	Section 39.3	N/A	Pass	3.3
Field Adjustable Trip Points	Section 39.4	N/A	Pass	3.4
Field Adjustable Trip Points, Marking	Section 39.5	N/A	Pass	3.5
Dielectric Voltage Withstand Test	Section 44	April 2, 1999	Pass	3.6
Output Ratings	Section 45.2	January 22, 2001	Pass	3.7
Harmonic Distortion	Section 45.4	January 26, 2001	Pass	3.8
DC Injection	Section 45.5	January 26, 2001	Pass	3.9
Utility Voltage and Frequency Variation	Section 46.2	January 24-25, 2001 February 9, 2001	Pass	3.10
Anti-Islanding	Section 46.3	January 22-23, 2001	Pass	3.11
Loss of Control Circuit	Section 46.4	N/A	Pass	3.12
Short Circuit	Section 47.3	February 9, 2001	Pass	3.13
Load Transfer Test	Section 47.7	N/A	Pass	3.14

3.0 Results Description

3.1 **Utility Disconnect Switch**: The microturbine complies with this requirement because it complies with Section 46.2, Utility Voltage and Frequency Variation Test.

3.2 Field Adjustable Trip Points: Section 46.2.4 requires that all field adjustable trip points be tested during type testing. Since this is not practical with our unit (there is an almost infinite number of settings that you could choose for under/over voltage and under/over frequency trip points), UL agreed to conduct the tests required by 46.2.4 over a sufficient range to demonstrate linearity and compliance. The microturbine therefore complies with this requirement because it complies with Section 46.2.

3.3 Field Adjustable Trip Points: A password is required to adjust the field adjustable trip points, and only service personnel have this password. The microturbine therefore complies with this requirement.

3.4 Field Adjustable Trip Points: The "Installation and Start-Up Manual" for the microturbine describes the trip time and adjustable ranges in addition to default factory settings. The microturbine therefore complies with this requirement.

3.5 Field Adjustable Trip Points, Marking: Section 63.2 requires that the microturbine be marked with the following electrical ratings: Maximum input current (not applicable); Operating voltage range AC (currently marked); Operating frequency range (currently marked); Nominal output voltage AC (currently marked); Nominal output frequency (currently marked); Maximum continuous output current (currently marked); Maximum continuous output power (currently marked); Nominal output voltage DC (not applicable); Voltage operating range DC (not applicable). As noted, the microturbine complies with this requirement.

3.6 Dielectric Voltage Withstand Test: This test is required to be conducted immediately following the Temperature Test, Section 43. Both tests were conducted and passed during our initial UL 2200 Listing Investigation.

3.7 Output Ratings Test: The output of the microturbine was verified to have a power factor of 0.85 or higher when connected to the utility and operated at 25, 50, and 100 percent of the rated output.

3.8 Harmonic Distortion Test: The total rms of the current harmonic distortion was verified to be less than 5 percent of the fundamental at full load. Individual odd harmonics were verified not to exceed the limits below, and even harmonics were verified to be less than 25% of the odd harmonic limits. The measurements were made with the microturbine delivering 100 percent of its rated output to the utility.

Odd Harmonics	Distortion Limit (percent)
3^{rd} through 9^{th}	4.0
11^{th} through 15^{th}	2.0
17^{th} through 21^{st}	1.5
23^{rd} through 33^{rd}	0.6
Above the 33^{rd}	0.3

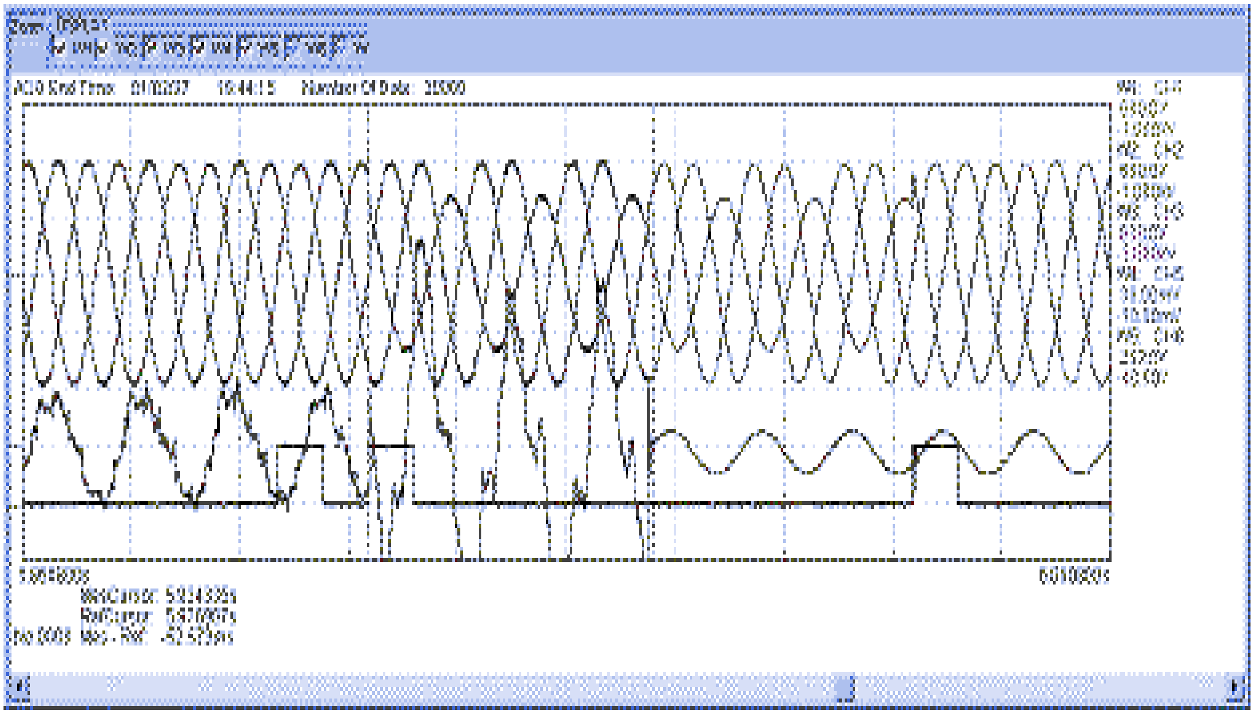
3.9 DC Injection Test: The microturbine was verified not to inject dc current into the ac output greater than 0.5 percent of the rated output current when connected to the utility. Since the rated output current of the Model 330 is 46 A, the measured dc injection was less than 230 mA.

3.10 Utility Voltage and Frequency Variation Test: The microturbine was verified to disconnect from the utility within the maximum allowable times shown below after the output voltage and frequency of the utility was adjusted to the test voltages and frequencies shown below. Each condition was repeated 10 times over a range of voltages or frequencies, as applicable, to verify compliance. For the voltage tests, it was verified that all 3 phases disconnected from the utility when any individual phase voltage of the utility was adjusted to the conditions shown below. It was also verified that the microturbine remained disconnected from the utility for at least 5 minutes when the automatic restart control was set to 5 minutes.

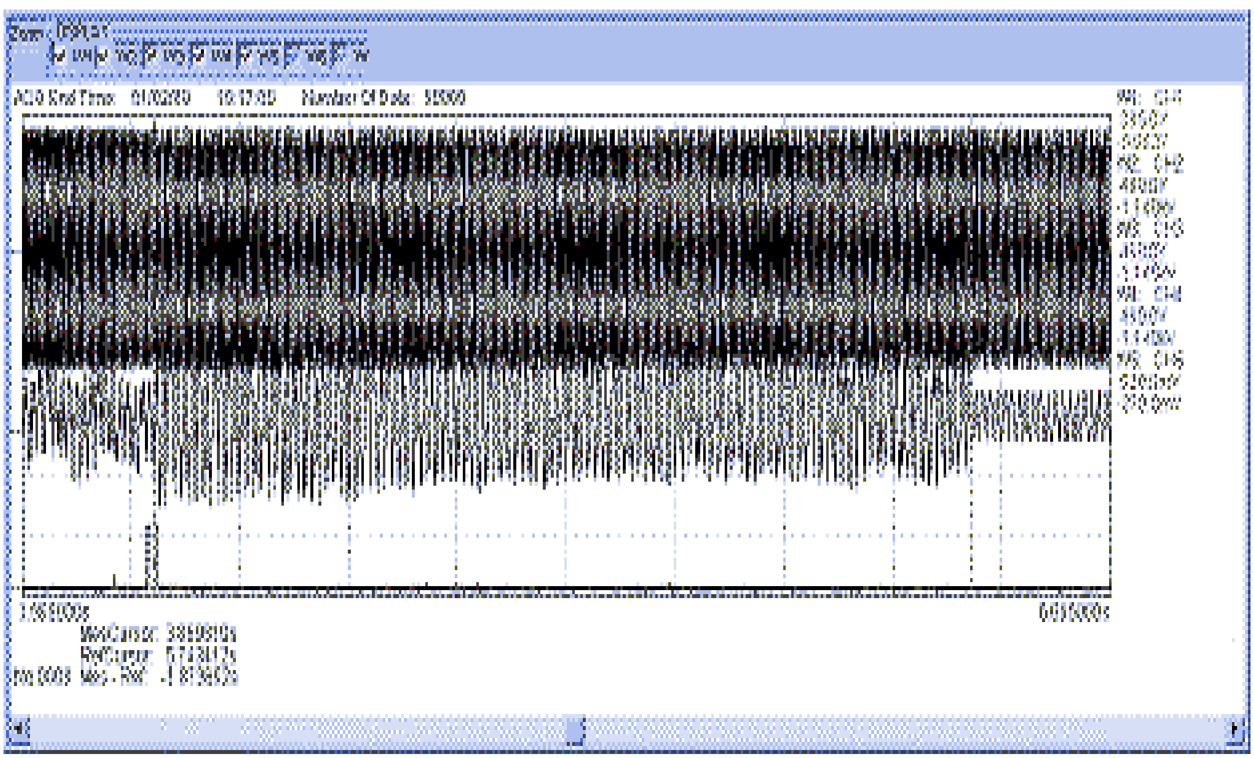
Condition	Requirement Voltage (V)	Test Voltage Range (V)	Requirement Frequency (Hz)	Test Frequency Range (Hz)	Maximum allowable time before disconnect (cycles)
A	240	340	60	60	6
B	422	413 – 422	60	60	120
C	528	509 - 528	60	60	120
D	657	531	60	60	2
E	480	480	< 59.5	59.4 – 58.5	6
F	480	480	> 60.5	60.6 – 61.5	6

A sample of plots captured on an oscilloscope during testing are shown below. The disconnect time was determined by measuring the time between the point at which the trip voltage was reached and the point at which the microturbine ceased exporting current on the output terminals (indicated by the beginning of the clean current signal).

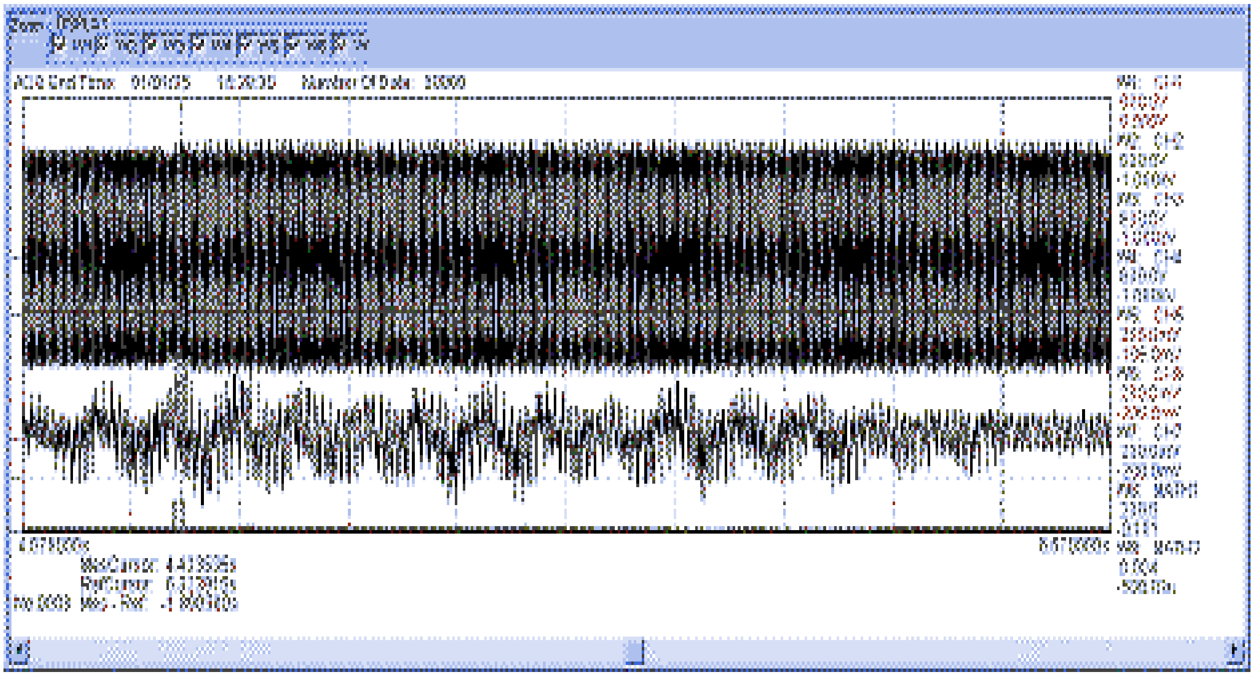
Condition A: Fast undervoltage at 340 V. Voltage on Elgar stepped to 331 V on Phase B. Time delay for relay = 10 ms. Trip time = ~53 ms.



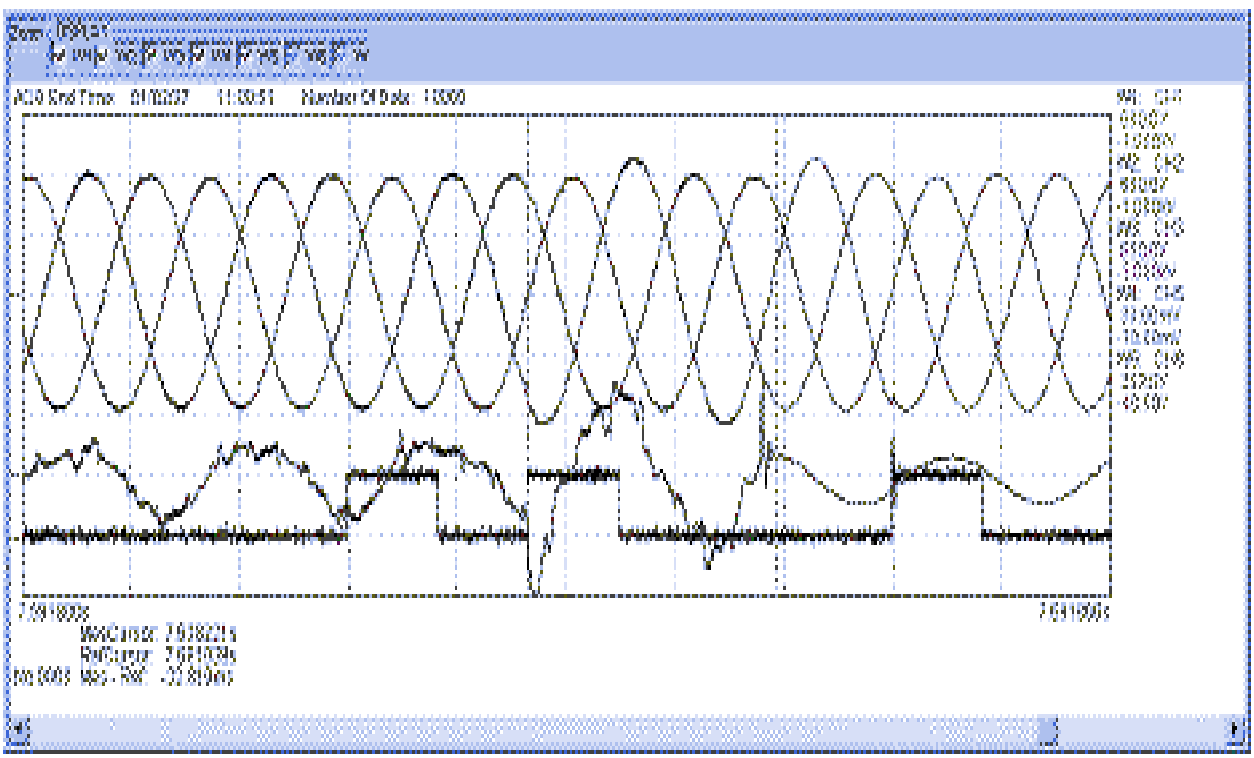
Condition B: Undervoltage at 422 V. Voltage on Elgar stepped to 419 V on Phase C. Time delay for relay = 1.8 s. Trip time = ~1.9 s.



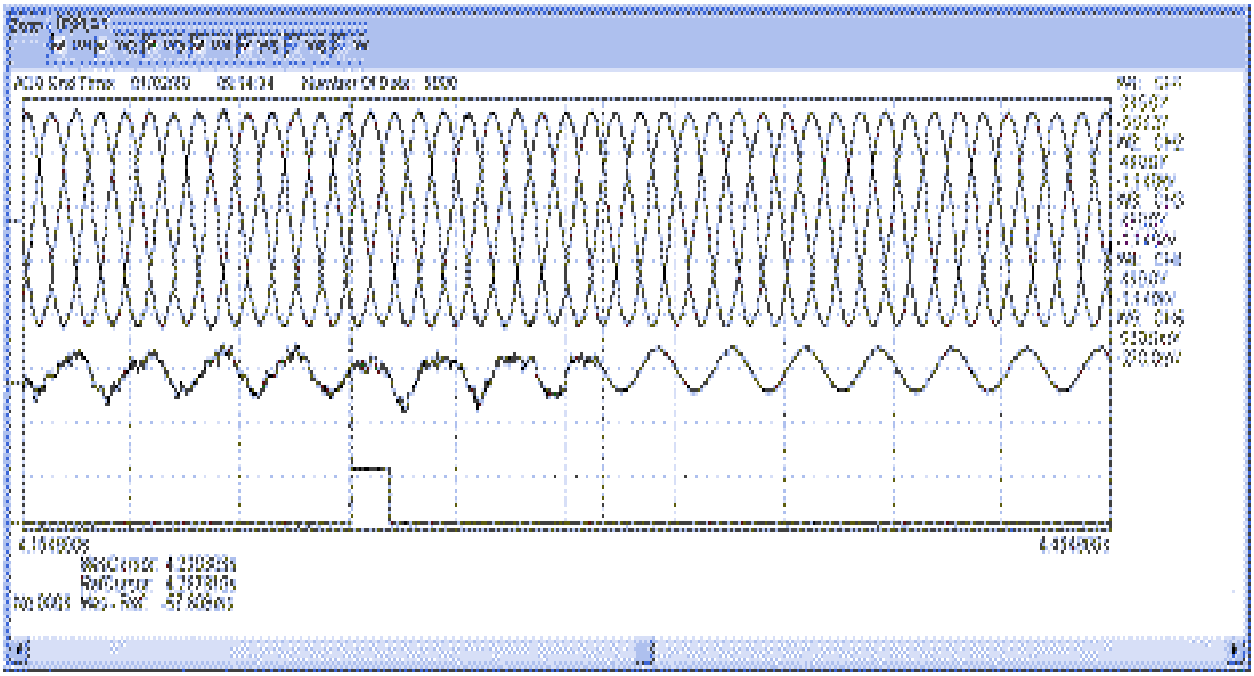
Condition C: Overvoltage at 528 V. Voltage on Elgar stepped to 533 V on Phase C. Time delay for relay = 1.8 s. Trip time = ~1.9 s.



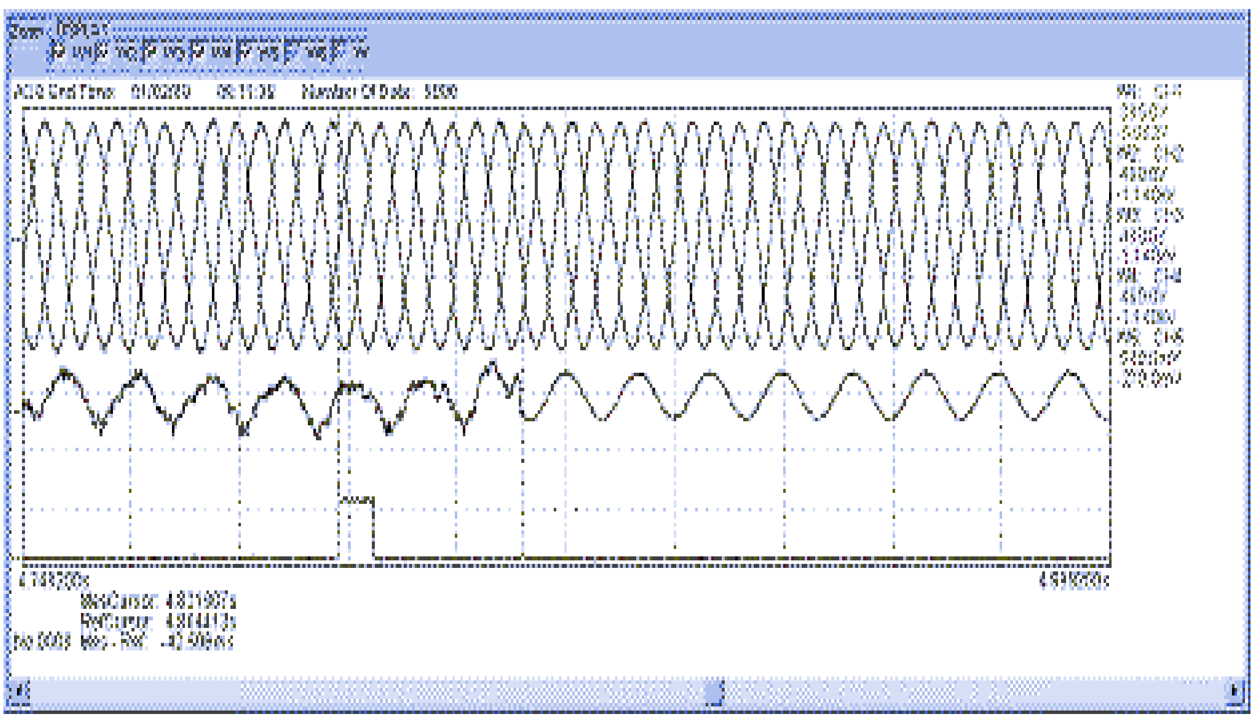
Condition D: Fast overvoltage at 531 V. Voltage on Elgar stepped to 540 V on Phase A. Time delay for relay = 10 ms. Trip time = ~23 ms.



Condition E: Underfrequency at 59.2 Hz. Elgar ramped from 60.0 Hz to 59.27 Hz in a time of 2 seconds, then stepped from 59.27 Hz to 59.2 Hz in a time of 1 cycle. Time delay for relay = 10 ms. Trip time = ~58 ms.



Condition F: Overfrequency at 60.6 Hz. Elgar ramped from 60.0 Hz to 60.5 Hz in a time of 2 seconds, then stepped from 60.5 Hz to 60.6 Hz in a time of 1 cycle. Time delay for relay = 10 ms. Trip time = ~42 ms.



3.11 Anti-Islanding Test: The microturbine was verified to cease power production to a balanced load circuit in less than 2 seconds after being disconnected from a simulated utility source. The load circuit was an RLC circuit that was set to have a quality factor Q of 2.5 or less, determined by the following equation:

$$Q = R \times (C/L)^{1/2}$$

In which:

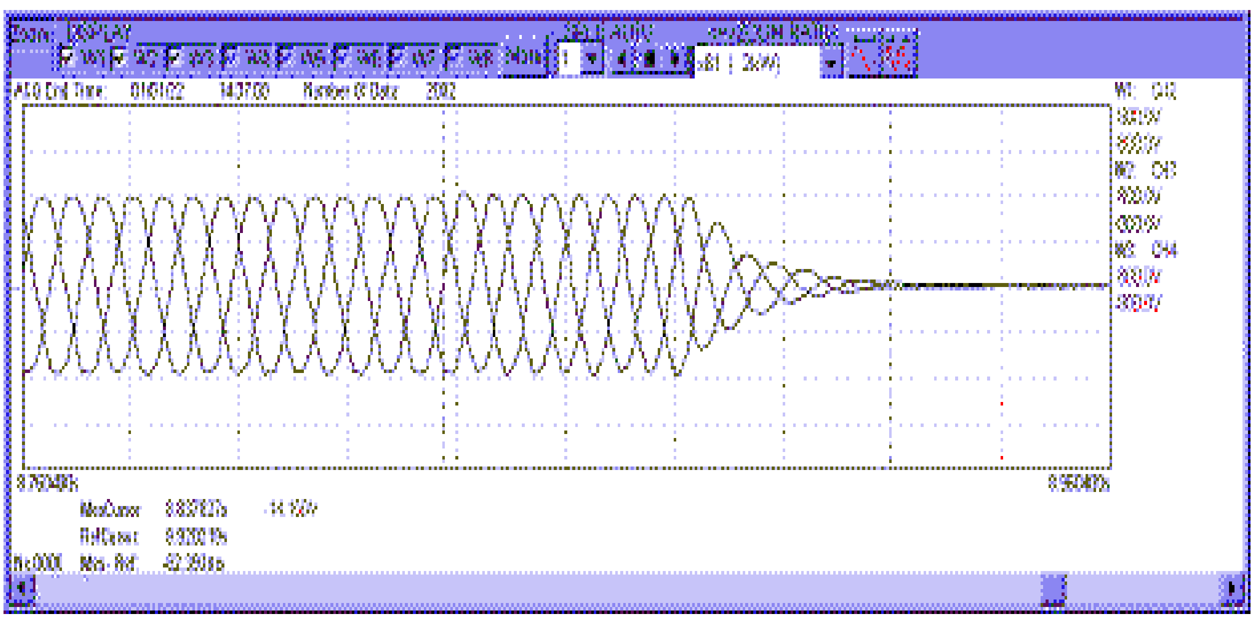
Q is the quality factor of the parallel (RLC) resonant load.
R is the effective load resistance in Ohms.
C is the effective load capacitance in Farads.
L is the effective load inductance in Henrys.

The test was repeated with the reactive load adjusted in 1 percent increments from 95 percent to 105 percent of the balanced load component value, and was conducted at the following test loads:

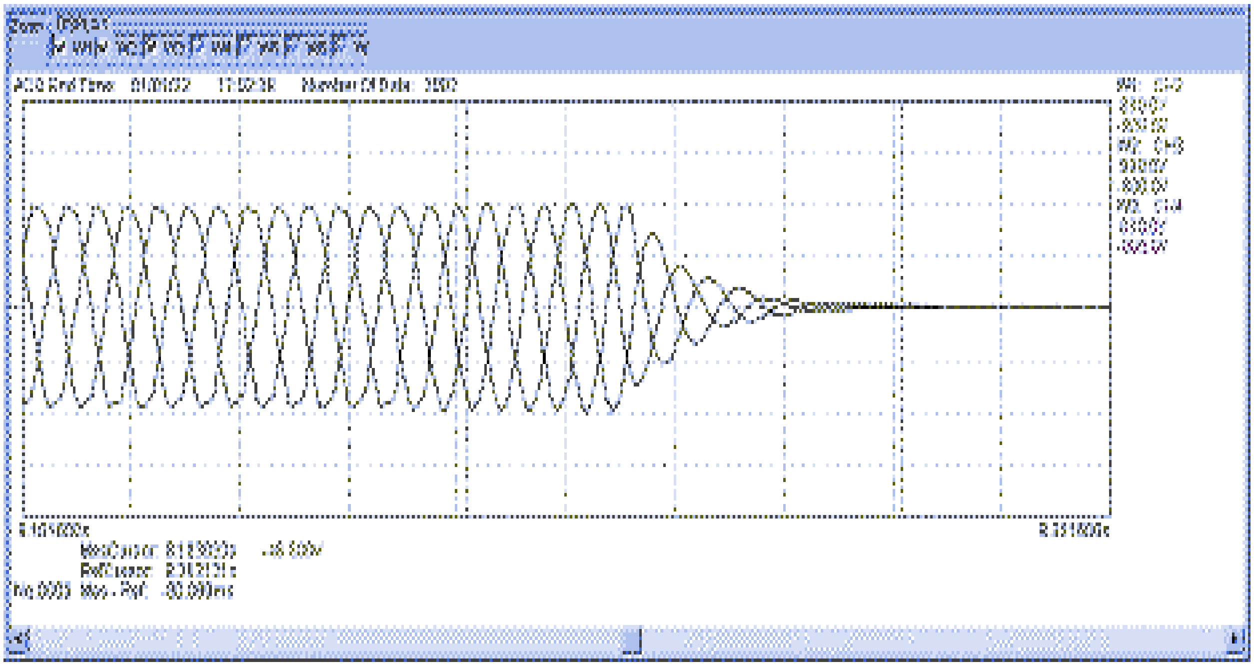
Real Load (percent of rated)	**Microturbine Output (percent of rated)**
25	25
50	50
100	100
125	100

A sample of plots captured on an oscilloscope during testing are shown below.

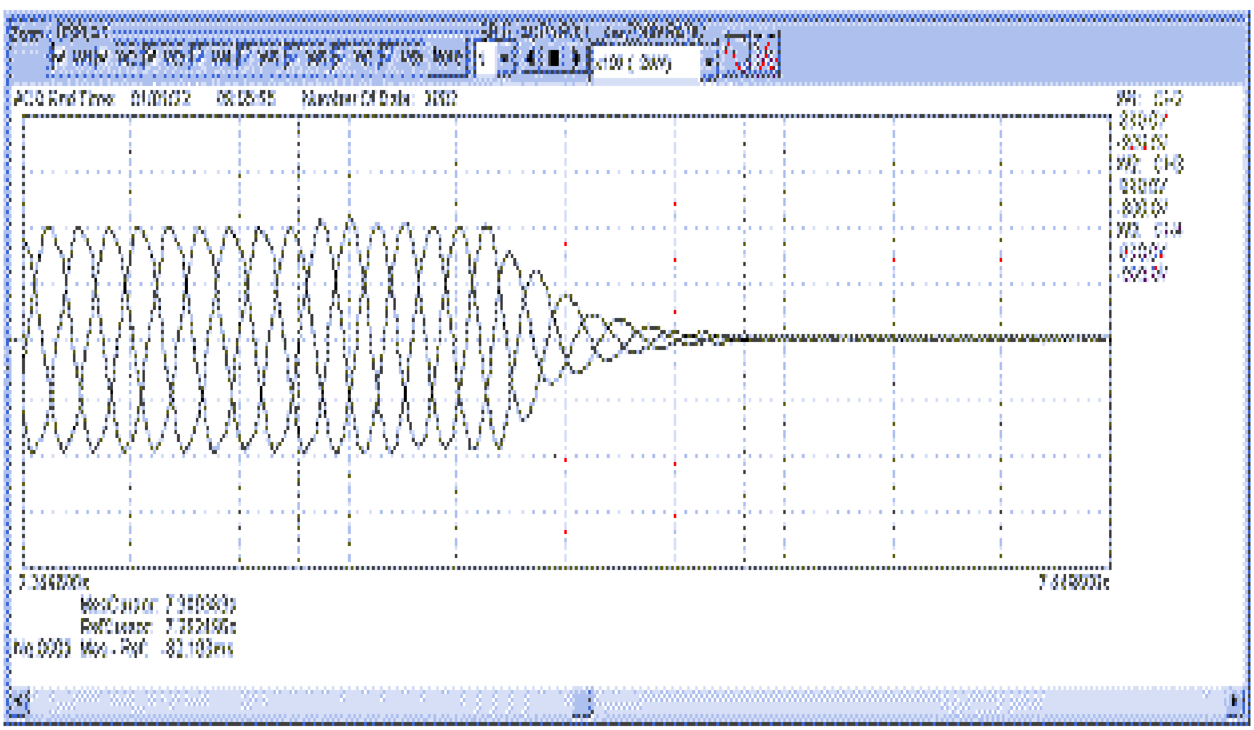
Condition 1: Real load = 25%. Microturbine output = 7.5 kW. Reactive load = 100% balanced load. Time to trip = ~82 ms.



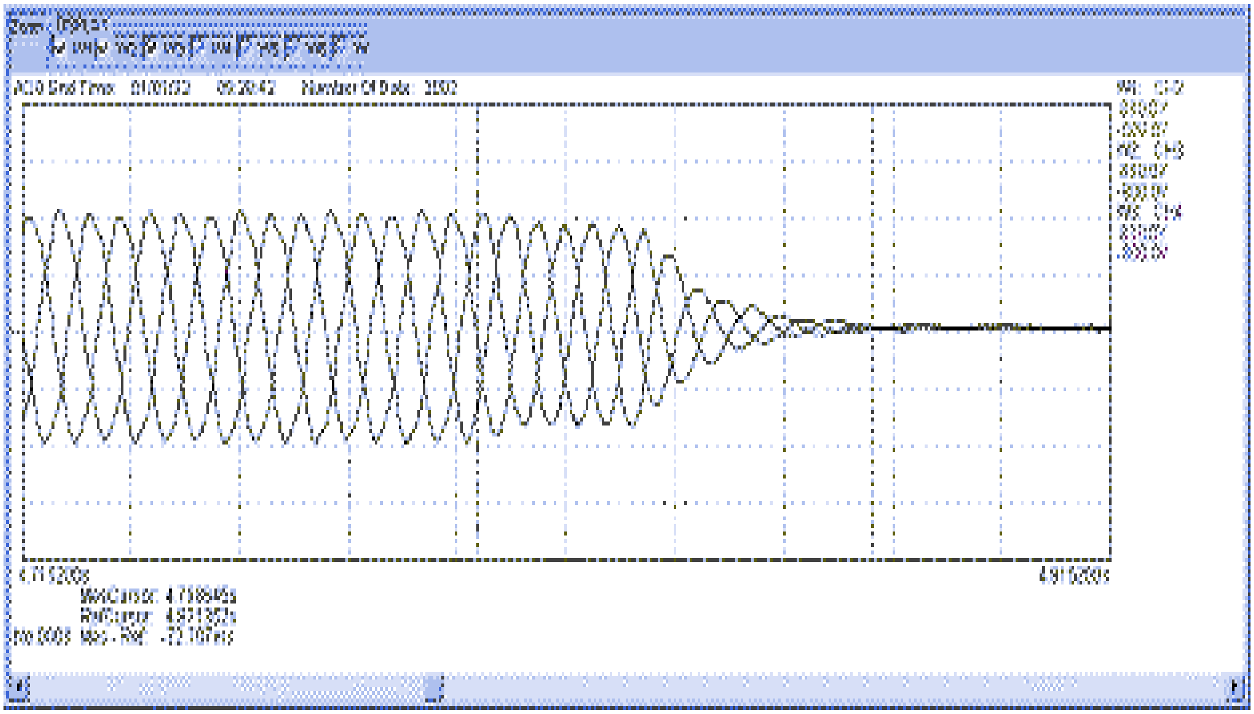
Condition 2: Real load = 50%. Microturbine output = 15 kW. Reactive load = 100% balanced load. Time to trip = ~80 ms.



Condition 3: Real load = 100%. Microturbine output = 30 kW. Reactive load = 100% balanced load. Time to trip =~82 ms.



Condition 4: Real load = 125%. Microturbine output = 30 kW. Reactive load = 100% balanced load. Trip time = ~72 ms.



3.12 **Loss of Control Circuit**: The microturbine control circuit is the DPC, specifically the control board. During our initial UL 2200 Listing Investigation, it was verified that when the control circuit is disabled, the unit shuts down and immediately ceases power production to the utility. The microturbine therefore complies with this requirement.

3.13 **Short Circuit Test**: The maximum microturbine output fault current was measured to be 46A. The measurement was taken immediately after the short was applied from phase to ground.

3.14 **Load Transfer Test**: The microturbine does not have a bypass switch, and therefore this test is not applicable.

4.0 Additional Tests for Rule 21

Section 3.g of Rule 21 requires that surge withstand capability testing be performed in accordance with the test procedures defined in IEEE/ANSI C62.45 using the peak values defined in IEEE/ANSI C62.41 Tables 1 and 2 for location category B3.

This testing was successfully completed on the Model 330 on July 3, 2001. Documentation will be forthcoming from NEMKO, the third party test laboratory that conducted the tests.

5.0 Default Protective Relay Settings

The default protective relay settings for the microturbine are as follows:

Fast Undervoltage: Default = 264 V, with a timeout period of 0.065 s. Voltage adjustment range = 0 V up to the Undervoltage relay setting, in 1.0 V increments. Timeout range = 0.001 s to 1.000 s, in 0.001 s increments.

Undervoltage: Default = 428 V, with a timeout period of 1.9 s. Voltage adjustment range = 360 V up to Overvoltage relay setting, in 1.0 V increments. Timeout range = 0.01 s to 10.00 s, in 0.01 s increments.

Overvoltage: Default = 524 V, with a timeout period of 1.9 s. Voltage adjustment range = 528 V down to the Undervoltage relay setting, in 1.0 V increments. Timeout range = 0.01 s to 10.00 s, in 0.01 s increments.

Fast Overvoltage: Default = 600 V, with a timeout period of 0.015 s. Voltage adjustment range = 600 V down to the Overvoltage relay setting, in 1.0 V increments. Timeout range = 0.001 s to 1.000 s, in 0.001 s increments.

Overfrequency: Default = 60.5 Hz, with a timeout period of 0.07 s. Frequency adjustment range = 65.0 Hz down to the Underfrequency relay setting, in 0.1 Hz increments. Timeout range = 0.01 s to 10.00 s, in 0.01 s increments.

Underfrequency: Default = 59.3 Hz, with a timeout period of 0.07 s. Frequency adjustment range = 45.0 Hz up to the Overfrequency relay setting, in 0.1 Hz increments. Timeout range = 0.01 s to 10.00 s, in 0.01 s increments.

6.0 Conclusion

The Capstone Model 330 microturbine meets very stringent safety and interconnection requirements, as embodied by the UL certification of compliance with UL 1741. A Certificate of Compliance is attached as Exhibit C.